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Liquidity contagion with a “first-in/first-out” seniority of claims

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Abstract

Building upon Lee (2013), this paper puts forward a methodological issue and presents a simple numerical example showing that the extent of systemic liquidity shortages due to a contagious funding run is strictly dependent on the seniority assigned to the different categories of claimants wishing to withdraw funds from financial intermediaries. In more detail, we find that a clearing payment algorithm based on the priority of interbank debt over depositors is found to potentially underestimate such liquidity shortages, if compared to a seniority rule working the other way round. This aspect may be of interest for supervisors implementing macro-prudential stress-testing exercises.

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1. Introduction

The aftermath of the 2007-09 global financial crisis has witnessed an upsurge of studies dealing with contagion in complex financial networks. Acemoglu *et al.* (2016) and Glasserman and Young (2016) provide excellent surveys to this exciting field of research. While usually focused on default cascades due to shocks affecting the assets side of intermediaries' balance sheets (Elsinger *et al.*, 2006; Gai and Kapadia, 2010; Battiston *et al.* 2012), starting with the work by Cifuentes *et al.* (2005), Müller (2006) and Gai et *al.* (2011) network-based contagion models has been progressively extended to study how idiosyncratic funding shocks can spread throughout an interconnected financial system. This latter perspective is the one we deal with.[1]

The goal of this paper is eminently of a methodological nature, which is to show that the priority of payments due to different categories of claimants during a systemic funding crisis is critical in assessing the final impact of a liquidity contagion. Among the various cascade mapping models existing in the literature, we elaborate on the one offered by Lee (2013), designed to measure systemic liquidity shortages.[2] As shown by Hurd (2016), this is the dual counterpart of the well-known algorithm by Eisenberg and Noe (2001), the only difference being that Eisenberg-Noe algorithm applies to default cascades (contagion from debtors to creditors), whereas Lee's dual algorithm (henceforth ENL algorithm) applies to liquidity contagion (from creditors to debtors, as in a bank run), which is our focus.

The ENL algorithm rests implicitly on three key technical assumptions:

a) A well-defined seniority structure in collecting money to pay back creditors, according to which a stressed bank mobilizes liquid and interbank assets first, and illiquid assets thereafter.
b) There are no losses in liquidating illiquid assets.
c) Interbank debt obligations are senior with respect to the repayments claimed by external depositors, even when the latter have been queuing for longer.

While the first two assumptions can be easily rationalized in terms of a crisis management institutional framework at work in preserving financial stability and a metric to measure its scale of operation, the third one implies an inversion of the seniority structure on the liability side of balance sheets implicit in the Eisenberg-Noe default resolution mechanism.[3]

The latter one is clearly at odds with what we observe during a systemic liquidity crisis. In the market-based financial architecture that emerged worldwide over the last three decades (Adrian and Shin, 2010), financial intermediaries can be exposed to an unforeseen wave of withdrawals not just from retail depositors, but also from short-term non-retail creditors that can refuse to rollover their funds almost overnight (Shin, 2009; Borio, 2010). When this occurs, external funding liquidity can suddenly dry up very quickly.

On top of this, recalls of interbank loans can add to the funding loss generated by the original wholesale depositors' run, but they typically result as a response to the contagion and therefore occur at a later time. Given that both demand deposits and overnight interbank deposits are entitled to be withdrawn at any time without any advance notice or at the least when a new working day begins, the postponement of payments due represents a breach of a contractual obligation that becomes more severe as the payment suspension time increases. If payments have to be made to claimants according to their order of arrival in an attempt to minimize legal

[1] For a literature survey, see Chinazzi and Fagiolo (2015).
[2] For a recent application of the model to real interbank data, see Gaffeo and Molinari (2018).
[3] See Assumption 1.1 in Hurd (2016, p. 31).

and reputational costs, the seniority of claims obeys de facto a "first-in/first-out" (FIFO) principle.

Our contribution is to show in a very simple setting that, compared to a FIFO seniority rule, assigning priority to interbank loans over depositors when payments to both categories are due means that during a contagion process a smaller amount of liquidity leaks out from the interbank market.[4] It hence follows that the systemic liquidity shortage recorded in equilibrium turns out to be underestimated and may result in a temporary misjudgment of the amount of additional liquidity required to minimize disruption in interbank markets. This issue can be relevant for supervisors interested in implementing macroprudential stress testing exercises (Dees *et al.*, 2017; Jobst *et al.*, 2017)) and fine-tuning system-wide liquidity needs estimates.

The remainder of the paper is organized as follows. Section 2 briefly recaps how Lee's model works and its main conclusions, and illustrates, by means of a simple numerical example, how the equilibrium in terms of systemic liquidity shortages changes when we assume that payments due to claimants are arranged according to the FIFO method as opposed to the priority structured embedded in Lee (2013). Section 3 wraps up the main results, discusses caveats and possible extensions.

2. Liquidity contagion with a FIFO seniority structure

Let us qualitatively discuss the baseline features of the model developed by Lee (2013) and its main conclusions before putting forward a numerical example that allows us to substantiate our research claim.[5]

Lee (2013) considers a set of banks interconnected among each other *via* a number of interbank claims. Each bank is endowed with a given quantity of liquid assets - which comprise cash reserves and interbank funds lent to other banks in the system - and illiquid assets. The sum of its assets must, of course, be equal to the sum of their liabilities made up by retail deposits, interbank borrowing, and bank equity.

Contagion dynamics are triggered by an exogenous bank run. When a bank experiences a deposit run, its managers activate a "contingency liquidity plan" to tackle this unforeseen event by disposing of readily available external liquid assets first, and recalling its interbank loans thereafter. The latter action will de *facto* act as a funding shock to its interbank debtors, and will hence spread contagion to other financial institutions. Once all liquid ammunitions have been exhausted, the bank will have, if needed, to retrieve additional funds by selling illiquid assets.

The central point of his analysis is to show that the total need of liquidity a bank faces has to take into account not only the depositors' withdrawal but also the liquidity calls by other banks. Whenever such liquidity needs of a bank exceed the value of its total liquid assets, bank-level liquidity shortages arise. The summation over all bank's equilibrium liquidity shortages returns systemic liquidity shortages, and those are shown to be substantially larger than the size of the initial run.

The model hinges upon the assumption that illiquid assets can be quickly sold at their face value. This is crucial, as it implicitly introduces the need for a sort of buyer- or lender-of-last-

[4] Our contribution, therefore, can be included in the literature – pioneered by Elsinger (2009) and surveyed by Glasserman and Peyton (2016) – aimed at incorporating into the basic Eisenberg-Noe framework realistic features like the presence of claims with different seniority, bankruptcy costs, non-linear asset recovery rates and fire sales.

[5] We refer the reader to Lee (2013) for a detailed technical account of the model.

resort (LOLR) capable to prevent fire-sale spillovers, and, it provides a straightforward interpretation to the systemic liquidity shortage ensued from contagion. This aggregate metric can indeed be read as the firepower any central bank must have as a ready-to-use weapon to prevent or curb illiquidity spirals in interbank markets and, as such, it pinpoints its scale of operation, i.e. the scale of liquidity injection that the LOLR must orchestrate to make the banking system viable when a contagion occurs. Real-world examples supporting the feasibility of both hypotheses abound. Think, for instance, of the Longer-Term Refinancing Operations launched by the ECB between 2011 and 2012, whose intent was that of providing emergency liquidity to banks by accepting bonds featuring various degrees of liquidity as collateral for 3-year loans. The €1.2 trillion advances issued by the ECB measured the systemic liquidity strain faced by the European banking system.

While it is easy to recognize the pivotal importance of correctly estimating the order of magnitude of such intervention, we maintain that the algorithm at the core of Lee's model is built in a way such that it systematically underestimates the required scope of such quantitative easing.

Let us now clarify our point, through a numerical example in which we consider a very simple financial system composed of just two banks endowed with the balance sheets reported in Table 1.[6] We then assume that bank A is disturbed by an idiosyncratic shock wiping out 100% of its deposits and let the contagion process start.

Table 1. Banks' balance sheets for the numerical example with 2 nodes.

Bank A			
Assets		**Liabilities**	
Interbank Loan to Bank B	1,00	Interbank borrowing from bank A	1,00
External Liquid Assets	0,00	External Deposits	1,00
External Illiquid Assets	2,00	Equity	1,00

Bank B			
Assets		**Liabilities**	
Interbank Loan to Bank A	1,00	Interbank borrowing from bank B	1,00
External Liquid Assets	0,00	External Deposits	0,00
External Illiquid Assets	0,00	Equity	0,00

We first derive what happens under the assumption that the seniority of payments is the one implicit in the iteration of the ENL fixed-point algorithm. The final ENL fixed-point solution is consistent with a dynamic process, which for clarity's sake can be split into the following subsequent time-steps:

- **Phase I**. Bank *A* experiences a run on its funding. The unexpected withdrawal of 1 unit is equal to its potentially available liquid assets (i.e. the sum of its interbank loan and external liquid assets), and hence *A* does not score any liquidity shortage at this stage. With no cash-reserves readily available, the liquidity contingency plan implies that *A* tries to call back interbank assets for 1. It must be noticed, however, that at this stage *A* is just a claimant of bank

[6] We have deliberately chosen two extremely simplified balance sheets that allow us to provide the main intuition without dealing with other second-order adjustments, none of which is critical to our point.

B, since the latter could not be able to fulfil its obligations on demand. As phase I ends, therefore, bank *A* has not succeeded in collecting any money to satisfy its depositors, who are still waiting for 1.

- **Phase II**. Bank *B* processes the *A*'s request to withdraw 1 from its interbank account. Given that such a sum is again equal to *B*'s available liquid assets (1), no liquidity shortages are formally recorded. *B* attempts to accommodate the request from A by resorting to the available liquid assets and calls back all its interbank loans towards *A* (1), At the end of the phase 2, *A* and *B* have reciprocal residual claims for 1 against their original interbank obligations.[7]
- **Phase III**. Bank *A* does not import yet any liquidity from bank *B* and cannot use it to satisfy the depositors who are still waiting for their money back. Bank *A* also imports a liquidity calling of 1 from *B*, but it has no liquid means to cover it. Hence, *A,* experiencing a liquidity shortage, is hence forced to sell some illiquid assets (1), and use the proceeds to repays its debt to *B*. At the end of phase III, bank *A* has paid off all its interbank debts, has still to receive 1 from *B*, while its depositors are still waiting for 1.
- **Phase IV**. *B* imports 1 of liquidity from *A*, and uses these proceeds to pay off its debt towards *A*.
- **Phase V**. *A* imports 1 of liquidity from *B*, and uses it to liquidate the depositors. At the end of phase V, therefore, the contagion stops.

The cumulative effect of the cascading shock is such that the liquidity shortages registered by bank *A* and bank *B* are equal to 1 and 0, respectively, which amounts to an injection of additional liquidity by the Central Bank of 1.

Let us now introduce a different hypothesis on the order of repayments by assuming that claimants are liquidated according to a FIFO seniority rule. This means that whenever a debtor has to repay two different creditors, the claimants who acted earlier has to be paid first. This introduces a significant modification of the contagion dynamics, that can be appreciated by retracing the whole process:

- **Phase I**. Unaffected.
- **Phase II**. Unaffected.
- **Phase III**. Bank *A* is waiting to recover its interbank assets and also imports a liquidity call from the bank *B* for 1, but it does not have any liquid assets to cover it. Since depositors are still waiting to receive their money back and must be paid before interbank counterparts, *A* is forced to ask the Central Bank a collateralized loan of size 2, large enough to meet both depositors' and interbank creditors' requests. At this stage *A*'s liquidity shortage is therefore higher than the one we scored in the previous case (1), and depositors' requests are fully serviced.
- **Phase IV**. Unaffected.

[7] The algorithm therefore assumes that interbank exposures are settled on a real-time gross basis, a settlement mode used, for example, in most unsecured interbank lending practices and modern large-value payment systems. This underlies, to a large extent, the difference between the ENL algorithm and a FIFO scheme. An alternative dynamic adjustment could be envisaged by allowing banks to net out their exposures in Phase II. While this would narrow or possibly even nullify the distance in terms of liquidity shortages between the two schemes, it can only work, in the absence of any central counterparty, for direct mutual exposures, where both banks are fully aware of the bilateral nature of their obligations. This may not be the case with longer chains of financial intermediation. For instance, suppose that bank B extends a loan to bank C, and this latter lends the same amount back to A. In this case, A and B have claims that could cancel each other out but the two banks are not aware of such possibility, provided that C keeps the identity of its counterparty private. For an exposition of the systemic consequences of allowing banks to bilaterally net their on-balance-sheet mutual obligations see Gaffeo *et al.* (2019).

- **Phase V**. Bank *A* receives 1 of liquidity from bank *B*, and the contagion process ends.

Summarizing, during the process bank *A* is required to increase its long-term collateralized borrowing from the Central Bank (+1), but when the contagion process ends it possesses an extra 1 of liquid external assets, ready to use in case a new withdrawal request occurs. Under the ENL scheme, the systemic liquidity shortage – as said before, a measure of the Central Bank's emergency liquidity injection aimed at preserving financial stability – is therefore underestimated by 50%.

Table 2 reports a comparison between the results in terms of systemic liquidity shortages obtained by means of the ENL algorithm, with those obtained by applying the FIFO principle, once again for the case of a network with N = 2. Under the current balance-sheet setting, for strictly positive shocks the absolute deviation between the two treatments is always positive and increasing with the size of the shock, reaching its maximum with a full run on deposits, leading to an underestimation of liquidity shortages as high as 50%.

Table 2. Absolute and relative difference in systemic liquidity shortages between the standard ENL algorithm and the FIFO seniority scheme for different levels of the exogenous shock.

Shock	**LS_ENL**	**LS_FIFO**	**Abs. Diff.***	**Rel. Diff. ****
1	1	2	1	0,5
0,9	1	1,9	0,9	0,47
0,8	1	1,8	0,8	0,44
0,7	1	1,7	0,7	0,41
0,6	1	1,6	0,6	0,38
0,5	1	1,5	0,5	0,33
0,4	1	1,4	0,4	0,29
0,3	1	1,3	0,3	0,23
0,2	1	1,2	0,2	0,17
0,1	1	1,1	0,1	0,09
0	0	0	0	N/A

* The absolute difference (Abs. Diff.) is computed as LS_FIFO - LS_ENL

** The relative difference (Rel. Diff.) is computed as Abs. Diff. /LS_FIFO

Intuitively, if both banks are contemporaneously hit by a non-bank creditors run, the distance of performance among the two treatments is *ceteris paribus* magnified. The FIFO seniority of payments due implies that any request from depositors has in such a case a priority over the liquidity requests from other banks. The greater is the number of banks facing a run on deposits, therefore, the greater is the number of holes through which liquidity flows out of the interbank system, forcing banks to ask for additional extra liquidity to the Central Bank.

3. Conclusions

Our exercise broadly speaks to the importance of checking the economic consistency of mathematical algorithms used in finance and economics. The aim of this note was indeed that of showing that a mechanical application of the ENL algorithm to the assessment of liquidity contagion requires an implicit and unrealistic assumption on the seniority of payments due to different categories of funding withdrawers that could bias the result of the analysis. In particular, the fact that different categories of creditors – like retail/non-retail depositors and overnight interbank lenders - have the right to withdraw essentially on demand implies that any deferral of repayment obligations involves costs that each financial institution should rationally seek to minimize. When facing a run, therefore, a bank is pressed to follow a FIFO principle when deciding on whom to repay first among all its short-term creditors and available liquid assets are constrained. By means of a simple numerical example, we showed that taking this issue into account in the ENL algorithm generates a dynamic adjustment toward the fixed point of the contagion cascade that have implications for the amount of emergency liquidity demanded during a crisis. Given the increasing importance assigned by supervisors to liquidity stress tests in mapping risks to financial stability and fine-tuning liquidity requirements, paying attention to the way alternative assumptions on the "micro-structure" of payments due might affect the dynamics towards the equilibrium of a cascade mapping is clearly of theoretical interest.

A number of caveats apply to our analysis and require an additional comment before setting out the possible extensions of our work. First, we do not investigate the distribution of liquidity beyond the end of the contagion process and, for this reason, we do not speculate upon balance-sheet adjustments that may take place after that point. This would in fact require a fully-fledged scheme to analyze the set of incentives/rules defining banks' liquidity management strategy. This is well beyond the scope of this short note and, at this stage, we shall like to point out that the timing of this repayment is uncertain and critically depends on market conditions. The excess liquidity, possessed by Bank A at the end of the contagion process under the FIFO rule, could/shall arguably be used to immediately settle its debt with the Central Bank. While this would make the FIFO liquidity amendment a temporary one, it is not unreasonable to envision, depending on the liquidity provision and redemption rules, commercial banks attempting to hoard central bank' funds for a longer period of time.

Moreover, even if one considers the additional liquidity injection (i.e. the one required when the FIFO principle is taken into account) as a short-term correction, we maintain that it is still relevant. This in fact may help provide a more accurate figure of the firepower any central bank may want to have as a ready-to-use weapon to manage illiquidity spirals in interbank markets.

Second, one may argue that a FIFO principle is simply not enforceable. Banks could in fact have an incentive to exploit asymmetric information to misbehave. Asymmetric information arises as the exact queue of creditors (and hence the expected correct order or payments) is only known by the bank itself. Some depositors may be unaware/uninformed of the other payment requests that the bank receives. As a consequence, a bank may very well decide to pay other banks first if this better suits its business plan. As previously pointed out, demand deposits and overnight interbank loans are legally entitled to be withdrawn without previous notice in the first case, and can be denied to be rolled over in a few hours in the second one. This means that in both cases the deferral of repayments entails legal and reputational costs snowballing as the payment suspension time increases. The FIFO principle is therefore in the best interest of banks, given that it represents a strategy to minimize these costs, and the recent financial crisis of 2007-08 is evidence of that. On the one hand, we have indeed witnessed several episodes of market freeze on interbank markets. On the other hand, despite the increase in deposit withdrawal requests banks have much more rarely failed to meet depositors' withdrawals requests (Tooze, 2018). In our view, an algorithm modelling a liquidity crisis must take factor in the correct (i.e. the empirically observed) pecking-order employed by modern credit institutions, which is what we attempt to do in this short note.

Third, in the model proposed by Lee (2013), retail deposits are the only exogenous source of contagion dynamics, and as such rank necessarily first in the payment order of arrival. This implies that applying a well-defined and empirically-based seniority of payments (i.e. one in which retail deposits are senior to interbank liabilities) delivers an order of payments which obeys *de facto* to a FIFO principle. In this case, seniority is by construction fully consistent with the order of arrival since deposits are the most senior funding instrument in the model and, at the same time, the starting point of the liquidity drain. Although this is simply the way the story works in the model (which we take as given) and not a general statement, we do believe that this is the most likely scenario. This is in fact based on the observation that recalls of interbank loans typically add to the funding loss generated by the original wholesale or retail depositors' run, and hence tend to occur at a later time.

With these caveats in mind, we feel that the most important and challenging way forward along this line of research would be to take the model to the data.

Indeed, our aim was to make a theoretical/methodological point. The numerical example here proposed is thought for this purpose, and is clearly far too simple to provide a guidance as to what the empirical value of the FIFO correction (or its order of magnitude) could be in real banking systems. Such assessment is well beyond the scope of this paper. On the one hand, this would entail much more work aimed at detailing a full analytical solution to the FIFO-augmented fixed point. On the other hand, the cost of such a programming effort could be more than offset by the benefit of being able to fully quantify empirically the bias discussed in this short note, understand its properties in a much more complex system than the one studied here, and ultimately gauge its practical policy importance. In fact, the size of the additional liquidity injection is clearly affected by the structure of funding (interbank markets vs retail depositors or wholesale investors) and the availability of high quality liquid assets whose effects could interact in non-linear ways. Considering the high cross-country heterogeneity along these dimensions[8], longer chains of financial intermediation, and increasingly tangled financial networks, FIFO corrections are likely to be quite diverse in different countries. This speaks to the importance, from a macro-prudential standpoint, of fine-tuning country-level liquidity adjustments.

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[8] For instance, Anglo-American bank funding is heavily reliant on deposits, whereas European models do so to a lesser extent and tend to exhibit a larger share of interbank borrowing (see Allen et al. (2018)). While exogenous shocks may be more dangerous in the former case, the transmission of the shock may be faster in the latter one. It is *a priori* hard to tell how these differences will play out in terms of potential ENL liquidity shortages and their FIFO-counterparts.

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